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RADIOACTIVATION OF THE NAL LINAC BY PROTON BEAM LOSSES: DESIGN CRITERIA FOR A BEAM LOSS MONITORING SYSTEM

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I. INTRODUCTION

The loss of protons during acceleration in the NAL 200 MeV linac will have two effects of significance from a radiation safety point of view. The first such effect will be the production of neutrons and prompt gamma rays when protons which are lost from the beam cause nuclear reactions in the linac drift tubes, creating a radiation hazard near the accelerator during its operation. The second effect will be the radioactivation of the drift tubes by these same reactions. If the residual activity remaining after the linac is turned off is sufficiently large, it will interfere with the linac maintenance and repair.

This note reports the results of a calculation of the fast neutron dose rates and of the residual gamma activity resulting from an assumed proton loss on copper drift tubes during linac operation.

It is suggested that the following upper limits on the exposure rate be adopted:

1. Routine daily maintenance of 1 hour per day: The dose rate should not exceed 10 mR/hr one foot from the linac tank after a one hour cooling-off period.

2. Infrequent work inside a linac tank: The dose rate should not exceed 25 mR/hr after an 8-hour cooling-off period.

The results of this calculation can then be used to get upper limits on the proton loss rate which will not activate the linac in excess of the above levels ("maximum tolerable loss rate").

The beam loss monitors being designed for the linac by the Radiation Physics Section will have sufficient sensitivity to detect the neutrons resulting from proton losses equal to 5% of this tolerable proton loss. In this way it will be possible to predict the exposure rate from residual activity that would result from continued operation of the linac under any particular conditions of proton loss. If the predicted exposure rate is too high, the linac operation can be adjusted <u>before</u> the problem of excessive induced activity manifests itself.

This memo gives only the results of this calculation; the details are contained in a separate appendix available on request.

II. METHOD OF CALCULATION AND RESULTS

The mean energies of the cascade and evaporation neutrons were calculated for each incident proton energy, T. These calculations are summarized in Table 1. This table also gives the neutron fluence at a radius of 1 meter from the beam line.

Table 1 also gives currents in an ionization chamber filled with C_2H_4. This information will be used in the design of linac beam loss monitors. The contribution to the current of prompt γ rays from proton-induced reactions was not taken into account because there exists no information on the number and energy of the gamma rays produced from a thick target. Any prompt gamma ray contribution to the current will in effect increase the sensitivity of the system to small proton losses.

The gamma exposure rates inside a linac tank after an infinite irradiation time and cooling times of 1, 3 and 8 hours, 1, 3, 10 and 30 days were calculated at five different proton energies and for four extreme shielding geometries. The infinite irradiation time was chosen to indicate the long-term results of a particular proton loss rate. Results for other irradiation times can be calculated on request.

The cooling times were chosen to be typical of the times one might expect to wait between beam turn-off and the start of a short or prolonged period of adjustment.

The first two shield geometries were relevant to the situation in which a person enters a linac tank for a prolonged period (30 cm from beam line), and has either no shielding or shielding by the full 40 gm/cm^2 of the drift tubes. The first case corresponds to the lack of shielding from activity that might be induced at the front face of a drift tube; the second case corresponds to shielding from activity created by losses inside the bore of the tube. The other two cases were for a position next to a linac tank (80 cm to beam line). The shielding thicknesses used were 20 and 60 gm/cm^2.

The fact that the drift tube bore is Monel 400 (67% Ni, 31% Cu) rather than pure copper caused some problems because there exists very little data relevant to the radioactivation of nickel by protons. The calculation was therefore done for a target of pure copper.

The maximum tolerable loss rates defined by the two criteria given in Section I turn out to be equal to within about 20%, which is less than the accuracy of the calculation itself. Therefore, only the results for the "infrequent maintenance" calculation are presented here.

III. RESULTS

Fig. 1 shows that the gamma ray exposure rate per proton lost is a sharply increasing function of proton energy. There are altogether ten curves: one for each of 5 cooling times and two shielding conditions. For any proton energy and cooling time the mean exposure rate per proton lost will be somewhere between the 0 and 40 gm/cm^2 curves.

Figure 2 shows the same data replotted with cooling time as the independent variable. It can be seen from the shape of the curves that for low proton energies the linac will cool down by a factor of 2 between 8 hours and 3 days after shutdown, after which its activity will remain rather constant in time. At higher proton energies the cooling will occur much less rapidly so that there would be little point in waiting more than 1 shift after shutdown before realigning drift tubes or performing long tasks.

The above comments pertain to equilibrium conditions which will exist after the linac has been operating for several years. For shorter irradiation times, the long-lived activity will not have reached equilibrium, and hence will not contribute as much to the gamma exposure rate. For shorter irradiation times, then, all the curves in Figure 2 will be lower and show much more pronounced cooling in the first few days after shutdown. Cooling curves for other conditions can be produced on request.

Let us define the maximum allowable continuous proton loss rate, $L_m(T)$, at any energy as that loss which will produce a 25 mR/hr exposure rate inside the linac tank. It will be prudent to use the data for 8 hours cooling and no shielding:

$$L_m(T) = \frac{0.025 \text{ R/hr}}{D(T, 8 \text{ hours}, 0 \text{ gm/cm}^2)}$$

Values for L_m are given in Table 2, along with the charge/ liter of C_2H_4 obtained under conditions of maximum proton loss:

$$Q_m(T) = L_m(T) \times Q(T).$$

The calculation of the activation of copper portions of the drift tubes by 38 to 200 MeV protons is most likely accurate to 30%, and for 10 MeV protons, to within a factor of two. Activation of the nickel in the Monel 400 drift tube bores is much harder to calculate because there is very little cross-section information available. What little information there is [1,2] indicates that nickel activation will produce a 3 to 4 times higher exposure rate than copper activation for the same irradiation conditions. This factor of 3 or 4 will be offset by the shielding effect of the quadrupole and drift tube body, bringing the exposure rates from nickel activation and 40 gm/cm^2 shielding down to the corresponding rates from the front face of the drift tubes with no shielding. The use of the 0 gm/cm^2 figures in setting maximum beam loss rates is therefore reasonable.

IV. CONCLUSION AND WARNING

Any ion chamber designed to monitor proton losses in the linac for purposes controlling the radioactivation of the machine should have sufficient sensitivity to detect proton losses equal to 5% of L_m; and should be able to measure losses equal to L_m with good signal to noise ratio.

It must be emphasized that the maximum tolerable losses given above were set solely on the basis of activation of the machine. The linac shielding may or may not be sufficient to protect personnel in the gallery or equipment area from losses which are allowed by the above criteria.

ACKNOWLEDGMENT

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REFERENCES

1. G. V. S. Rayudu, Can. J. Chem. 42, 1149 (1964).
2. K. S. Toth, C. B. Fulmer and M. Barbier, Nucl. Inst. & Meth., 42, 128 (1966).

Table 1.

Incident Proton Energy T	Cascade			Evaporation			
	Neutron Yield Y	Mean Energy $\bar{E}$ (MeV)	Fluence F (n/cm^2)	Neutron Yield Y	Mean Energy $\bar{E}$ (MeV)	Fluence F (n/cm^2)	Charge Per Liter Q
200 MeV	0.204	11.9	3.25×10^{-6}	0.530	2.78	8.44×10^{-6}	3.10×10^{-20} Coul.
175	0.150	9.68	2.39×10^{-6}	0.417	2.67	6.64×10^{-6}	2.30×10^{-20}
125	0.078	5.80	1.24×10^{-6}	0.226	2.39	3.60×10^{-6}	1.13×10^{-20}
75	0.025	2.59	4.0×10^{-7}	0.086	2.00	1.37×10^{-6}	3.62×10^{-21}
37.5	0.0052	1.10	8.3×10^{-8}	0.020	1.66	0.32×10^{-6}	7.13×10^{-22}
10	0.001	1.	1.6×10^{-8}	---	--	-----	2.4×10^{-23}

Neutron yields at various incident proton energies.

The neutron fluence, F, is evaluated at a radius of 1 meter from the beamline; and at an assumed proton loss of 1 p/m.

Q is the charge liberated in 1 liter STP of C_2H_4 under the above conditions.

Table 2.

T (MeV)	L_m (protons/m-sec)	Q_m (coul/sec)	Q_p (coul/pulse)
200	4.8×10^{9}	1.49×10^{-10}	4.58×10^{-11}
175	6.25×10^{9}	1.44×10^{-10}	4.43×10^{-11}
125	1.56×10^{10}	1.72×10^{-10}	5.29×10^{-11}
75	6.4×10^{10}	2.32×10^{-10}	7.13×10^{-11}
38	1.32×10^{11}	9.3×10^{-11}	2.86×10^{-11}
10	8.3×10^{11}	2.0×10^{-11}	6.15×10^{-12}

The maximum allowable continuous proton loss, L_m, and the current/liter STP, Q_m, in a C_2H_4 filled ionization chamber resulting from a loss of L_m (T) protons of energy T. The charge collected per linac pulse, Q_p, is based on 13 linac pulses every 4 seconds.

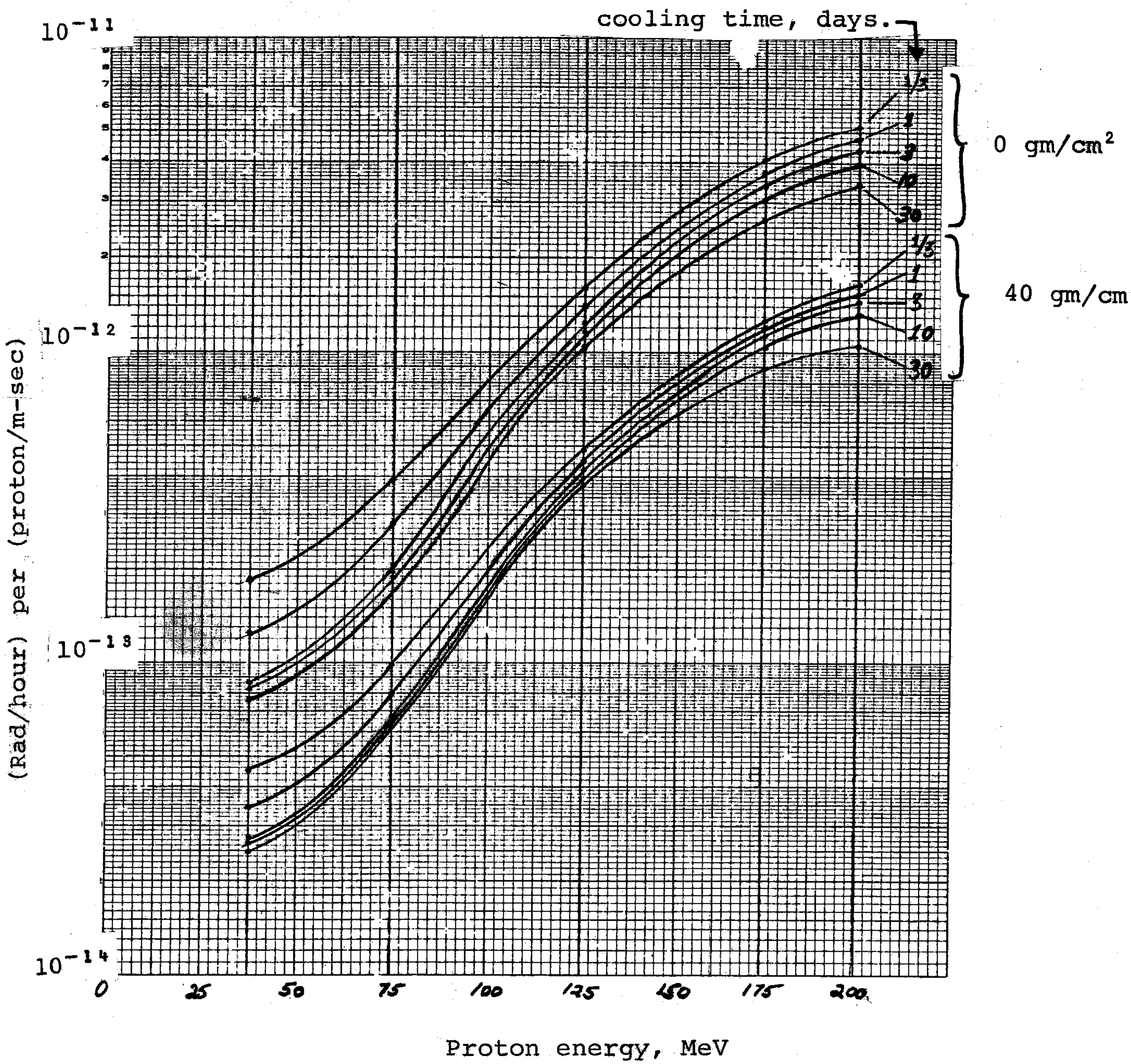

Figure 1. Gamma ray exposure rate inside a linac tank resulting from a continuous loss of 1 proton meter-second inside a drift tube. Curves are plotted for 0 and 40 gm/cm^2 shielding and cooling times ranging from 1/3 to 30 days.

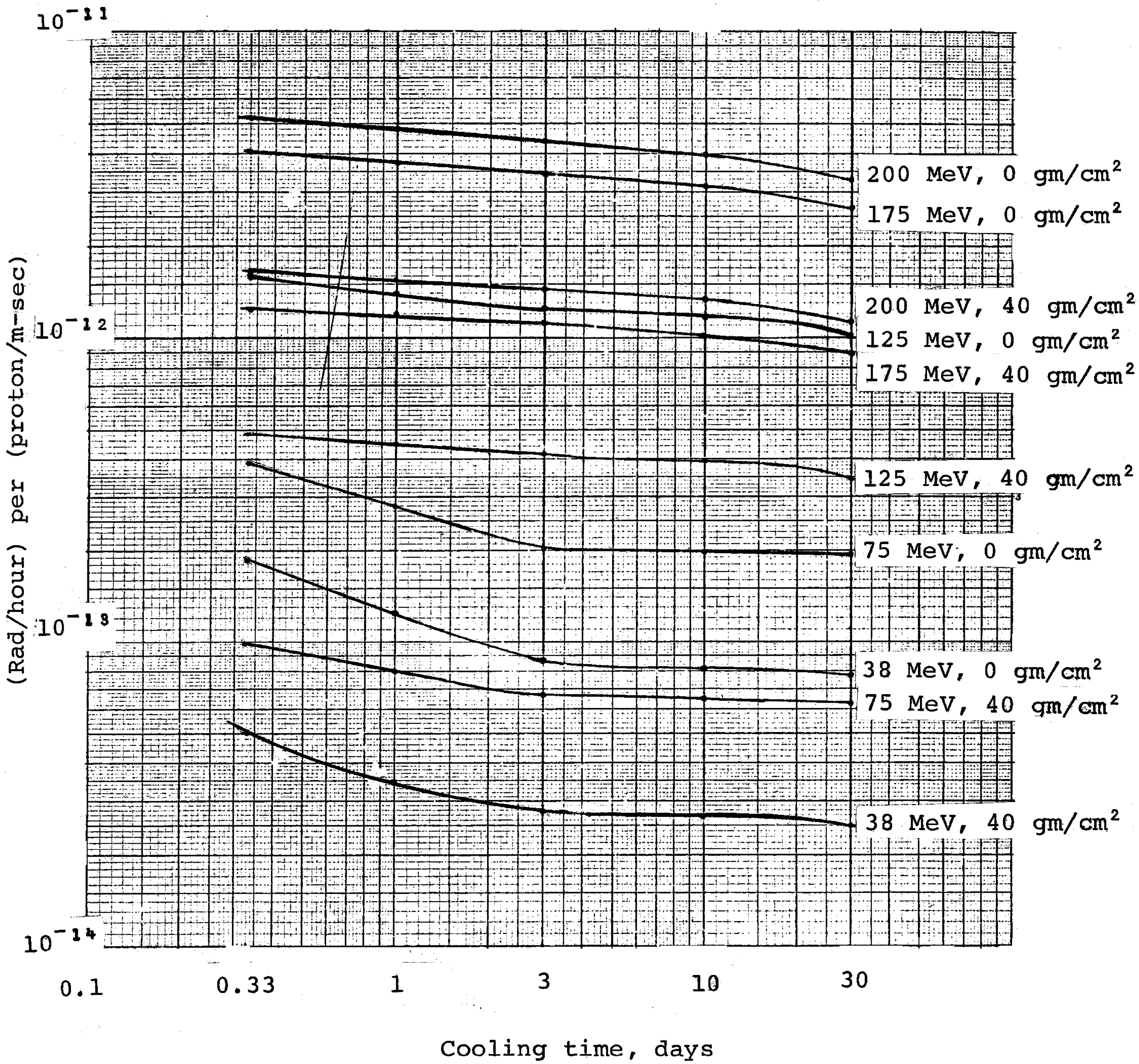

Figure 2. Reduction with time of the gamma ray exposure rate inside a linac tank resulting from the continuous loss of 1 proton/meter-second inside a drift tube. The proton energy and shielding provided by the drift tube are parameters.